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ABSTRACT

This document reports on an educational research study involving 75 eighth-grade students to determine the effects of problem solving instruction on the ability of students to apply proportional reasoning in problem situations. Results suggest that changes in basic reasoning skills such as proportional reasoning are long term, highly dependent on general formal capabilities, and probably responsive to a variety of instructional modes. (SL)

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Interaction of Formal Operational Capability and Instructional Feedback Mode

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A paper presented at

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Science education curriculum developers have advocated the use of concrete experiences in instruction intended to promote the development of logical thought. Science education research (Raven, 1974; Lawson and Wollman, 1976; Arons, 1974; Boulanger, 1978; Levine and Linn, 1977) has generally supported this position. Some research, while accepting their affective value, has cast doubt on the cognitive necessity of such experiences (Herror, et. al., 1976). Inhelder, Bovet, and Sinclair (1974) stated that whatever the mode of communication between subject and information source, the primary consideration is that the opportunities for intellectual activity correspond to the subject's level of development. For example, among persons in the late concrete operations stage, opportunities appropriate to the development of proportional reasoning would be those which allow the discovery of compensations in the concrete mode since recognition of compensations preceeds the recognition of proportions (Inhelder and Piaget, 1958, p. 221).

As the formal reasoning capability increases, the need for concrete experience diminishes since the person becomes more able to assimilate and operate on information in symbolic form. For example, if a person has a developed capability with proportional reasoning, there is little need to first work through compensations in the concrete mode to construct proportional relationships between variables. This developmental model implies that an aptitude-treatment interaction should occur wherein persons with undeveloped formal capabilities should find concrete based instruction more conducive to the development of such capabilities and persons with developed formal capabilities should find different levels of instruction on the concrete-symbolic

continuum equally adequate. This assumes that the substantive information needed for instructional problem solving is available at any point along the continuum; only the mode by which the information is obtained and the attendent opportunities for self-initiated exploration differ.

In addition to cognitive outcomes dependent on the match between capability and treatment, certain attitudes toward the treatments should pervail. Persons with undeveloped formal capabilities should be more favorably disposed toward concrete based instruction since it matches their developmental level, while those with developed capabilities may enjoy work with real objects but find more symbolic based instruction equally desirable.

Purpose and Design

The purpose of this study was to apply the above analysis to the design of two instructional treatments suitable for an eighth grade physical science course and to test the treatments in a naturalistic setting. Each of the two treatments would promote the development of proportional reasoning using different modes. Interaction effects between the three treatments (control included) and pretested formal operational capability would be investigated, along with main effects, in terms of dependent measures of proportional reasoning and attitude toward the instruction. Since the naturalistic setting would require the use of non-randomized intact groups, multiple regression analysis of covariance would be applied to control for initial differences in formal operational capability.

Treatments

The study compared three treatments: Verbal Manipulative (V-M), Verbal-Pictorial (V-P) and a non-intervention, regular instruction control. The V-M treatment was designed first with the V-P treatment patterned after it. The control group studied related, but not identical topics.

Four introductory problems and three extended activities requiring the application of proportional reasoning were created. The objective common to each problem and each activity was to provide opportunities for the student to construct proportional relationships and make testable predictions based on these relationships. The four problems were measurable illustrations with directions. The problems were adaptations of the Mr. Tall problem (Karplus, et al., 1977), the similar rectangles task (Piaget and Inhelder, 1967), speed comparison problems (Boulanger, 1976) and the pizza puzzle (Karplus, 1977). After the students worked these problems as best they could, the teacher reviewed each problem using the review to introduce and emphasize the common theme of proportions required for solution. All students had had earlier experience in various mathematics classes with solving numerical proportions, but no experience in constructing proportions in the context of physical science.

The second stage of the instructional sequence required application of proportional reasoning to physical situations. The format for the activities followed that developed by Linn, Chen and Thier (1977) for use in a free choice environment. The first activity required the student to identify and explore the variables affecting the motion of a sphere rolling down one incline

and up a second incline. The student then took measurements which resulted in proportionally related ordered pairs of distances on the two inclines. The students were challenged to first make, then test, predictions based on the pattern in the data. The variables of incline steepness and type of ball were varied, additional data collected, new patterns sought, and new predictions tested on the apparatus.

The second activity followed the same pattern as the first. Students identified and explored the variables affecting the sinking and floating of regular shaped objects of different materials. The qualitative experience was followed by mass and volume measurements of different regular shapes of aluminum. These measurements also generated proportionally related ordered pairs of numbers. Students were again challenged to make predications based on the pattern in the data and to test the predication with actual objects. New data on the ratio of mass to volume of several different materials was collected and compared. The amount of mass associated with one unit of volume was used to make predications about sinking or floating in water. Density as a constant ratio for different masses and volumes of a given material was stressed.

The final activity was a quantitative investigation of the balance beam. Data was collected and analyzed to discover proportionally related variables.

After each of the three second stage activities, the teacher discussed with the entire class the patterns in the data collected, always emphasizing the presence of proportional relationships in apparently unrelated phenomena.

The treatment described above was the Verbal Manipulative (V-M) treatment. The same treatment without manipulatives was the Verbal-Pictorial (V-P) treatment. In this latter treatment, all data was

provided under tabs which were removed one at a time as the student worked through the various problems presented. The problems were structured such that a solution or measurement had to be predicted or estimated before feedback, via tab removal could be obtained. In the V-M treatment, basically the same quantitative feedback was available through direct observation and measurement.

Instruments

Keeping in harmony with the naturalistic orientation of the study, two instruments, designed for classroom teacher use were chosen. Lawson's (1977) Classroom Test for Formal Operations was given as a pretest measure of each student's present formal operations capability. The test consisted of fifteen teacher demonstrations, each requiring a student written explanation of the reasoning used in solving the problem posed. The test has been validated against Piagetian interviews (correlation .76) and has a reported KR20 reliability of .78.

The second instrument, chosen for use as a dependent measure, was a multiple choice test of proportional reasoning for junior high pupils (Rudd, 1977). This 24 item, multiple choice test was also validated against Piagetian stages (correlation .36) and reported a KR20 reliability of .78. Although the 24 items were divided into four Piagetian stage related categories, the instrument was used in this study to define a continuous variable, proportional reasoning, with a potential score range of 0 to 24. This use of the instrument appeared justified by the great overlap of item difficulty across stages.

To measure the favorability of student attitudes toward the instructional experience, a 12 item agree/disagree Student Opinion Survey was

designed (see Appendix). Face validity was assumed in designing four sub-categories (Interest, Clarity, Appropriate Difficulty, Preferred Mode) of three items each as components of the attitudinal measure.

Subjects

Three eighth grade physical science teachers with seven classes of students participated in the study. The classes were located in two junior high schools in a middle class, socially and racially integrated close-in suburb of Chicago. Since the V-P treatment departed most notably from the regular school curriculum, only one class (N=17) used these materials. The V-M materials were used by three classes (N=58). The remaining three classes continued with the regular text book based program, studying related, though not identical, content (mass, area, and volume calculation and measurement). There was no random assignment of either teacher or students to treatments. Each teacher used only one treatment.

Pretesting revealed initial differences among the groups in formal operational capability. The V-P group scored significantly ($p < .05$) higher than the other two groups which were not significantly different. Later, California Achievement Test records showed the same relationship among the three groups. Subsequent analysis of covariance would correct for these differences.

Procedure

To keep the naturalistic setting as completely intact as possible, the regular teacher performed all testing and instructional tasks and student groupings remained as was the practice before the experimental materials were introduced. The only exception was the administration of the pretest and posttest to the control group by the researcher.

The two instructional treatments were conducted early in the school year (October). Both teachers had dealt with approximately the same material from the same textbook prior to the treatment. Each teacher was briefed on the proper administration of the tests and the use of the instructional materials. The researcher was in daily contact with the teachers during the experimental period.

An initial effort to have students record the actual time spent working on the materials was quickly frustrated. Time spent on each instructional treatment was recorded in terms of daily forty minute class periods. The V-M treatment required 13 periods while the paper and pencil based V-P treatment required only 9 periods. These time periods were determined largely by teacher judgment of student progress in completing all tasks required in the materials.

Normal patterns of student social interaction were not disturbed. Lab partners continued to work together, discussing freely all aspects of the activities, whether in the V-M or V-P treatments. The control group also continued its normal activity, interupted only by the pretesting and post-testing, timed to correspond approximately with pre and post testing of the instructional treatment groups.

Given the naturalistic style of the research, it must be assumed that many variables went uncontrolled. The researcher claims only that the primary causal variable during the period of instructional treatment was the content and structure provided by the mateirals and faithfully interpreted by willing, cooperative and capable teachers.

Data Collection and Analysis

The Classroom Test of Formal Operations was administered just prior to the initiation of the instructional treatments. Due to the defective administration of three of the test's fifteen demonstrations, only twelve items were used in the final data analysis. (Total scores based on the twelve items were found to correlate .98 with scores based on all fifteen items for the 122 cases where all demonstrations were properly administered).

The Proportional Reasoning Test was administered on the day following the last class session on the instructional treatment. This meant that the V-M group took the test 4 days after the V-P group. The Student Opinion Survey was administered immediately following the density activity, the longest activity of the instructional sequence.

Data from the three measures was analyzed in two steps. First, a bivariate regression of each dependent variable on to the Classroom Test of Formal Operations was performed. Tables 1 and 2 summarize these regressions for the proportional reasoning and student opinion measures respectively. Figures 1 and 2 are the regression lines ploted using the slopes (B) and constants from Tables 1 and 2 respectively. For ease of analysis and comparison between plots, the grand means and the related standard deviations were used as a basis for ordinate subdivision.

It should be noted that the n values on the Student Opinion Survey were considerably smaller than those on the proportional reasoning test. This is due to incomplete or uncertain student responses on opinion survey items, causing the student's total survey to be rejected from the analysis.

Table 1

Bivariate Regression of Proportional Reasoning (Dependent) with Formal Reasoning for Each Treatment

Treatment	n	R	R^2	B	Constant	p
Verbal Manipulative	58	.46	.22	.55	10.85	.000
Verbal-Pictorial	17	.67	.45	.76	11.55	.002
Control	64	.47	.22	.76	8.38	.000

Table 2

Bivariate Regression of Favorability of Student Perception of Instructional Treatment (Dependent) with Formal Reasoning for Each Treatment

Treatment	n	R	R^2	B	Constant	p
Verbal-Manipulative	31	-.15	.02	-.15	21.47	.211
Verbal-Pictorial	9	.83	.68	.58	16.78	.003
Control	43	.32	.10	.45	17.39	.017

Figure 1

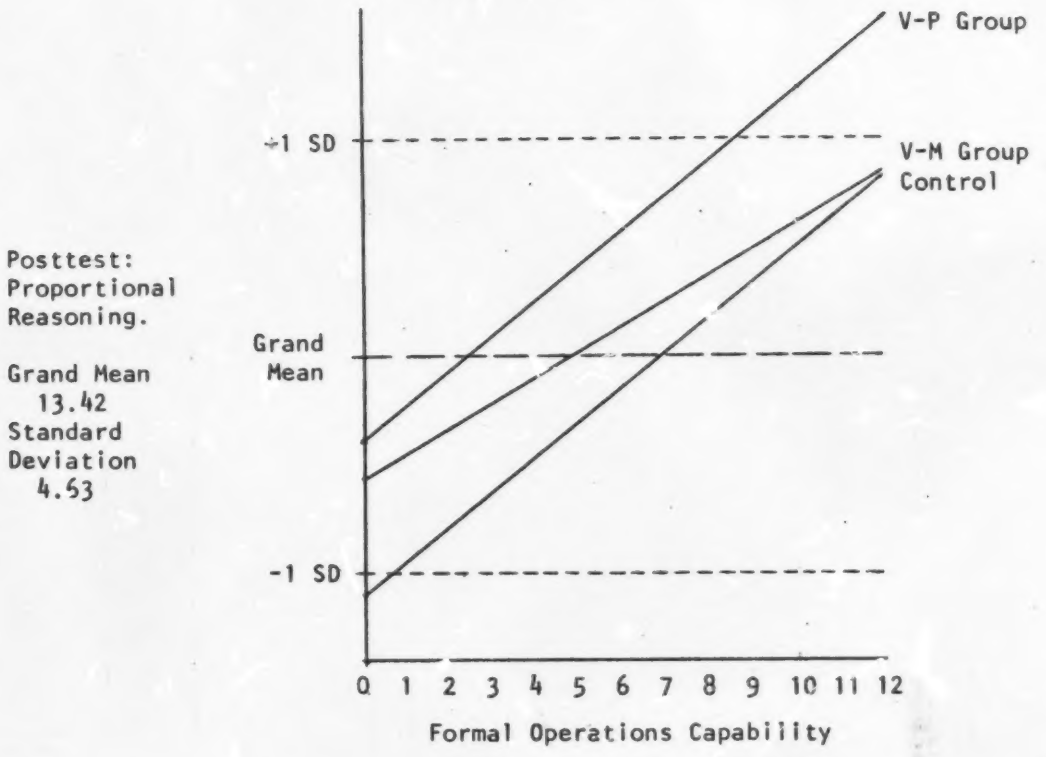
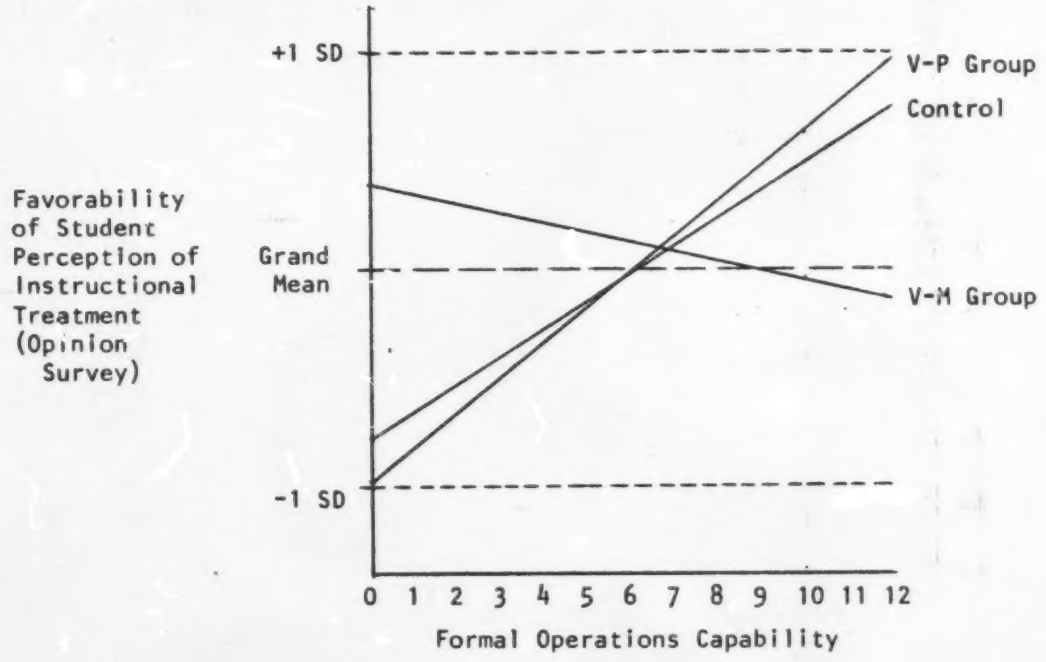


Figure 2



The second stage of data analysis was application of multiple regression analysis of covariance seeking evidence of main and/or interaction effects between the three treatments and the covariate, formal operational capability. Tables 3 and 4 summarize the multiple regressions with proportional reasoning and favorability of student perceptions as dependent variables respectively.

Results and Conclusions

Table 3 provides evidence of significant main effects due to both treatment (T adjusted for F, $P < .01$) and formal operational capability (F adjusted for T, $p < .001$). There is, however, no evidence of interaction between treatment and formal capability as these two variables affect proportional reasoning outcomes. The main effect of formal capability was expected, since it was chosen as a covariate. Bivariate regression analysis (Table 1) indicated that the two measures (Classroom Test of Formal Operations and the Proportional Reasoning Test) have an approximate correlation of .5.

Controlling for formal operational capability, comparison of treatment means indicated that the significant difference was between the V-P group and the control ($p < .05$) with the V-M group occupying a midway position not significantly different from the other two groups. No particular value in the use of manipulatives to promote proportional reasoning was revealed in this analysis.

Table 4 in conjunction with Figure 2 gave a fairly clear finding as to the value of manipulatives. The significant ($p < .05$) interaction between

Table 3

Multiple Regression Analysis of Covariance Summary Table

Dependent Variable: Proportional Reasoning
Independent Variable (Categorical): Treatment (T)
Metric Covariate: Formal Reasoning (F)

Source		R^2	df	F	p
(1) T and F (saturated)	$R^2_{T,F,TF}$	.3357	5	13.44	.001
(2) T and F (additive)	$R^2_{T,F}$	.3298	3	22.01	.001
(a) T adjusted for F	$R^2_{T,F} - R^2_F$	.0566	2	5.67	.01
(b) F adjusted for T	$R^2_{T,F} - R^2_T$	.2134	1	42.73	.001
(3) Interaction T X F	$R^2_{T,F,TF} - R^2_{T,F}$	.0060	2	0.60	
(4) Residual	$1-R^2_{T,F,TF}$	.6643	133		

Table 4

Multiple Regression Analysis of Covariance Summary Table

Dependent Variable: Favorability of Student Perception of Materials
Independent Variable (Categorical): Treatment (T)
Metric Covariate: Formal Reasoning (F)

Source		R^2	df	F	p
(1) T and F (saturated)	$R^2_{T,F,TF}$	.1384	5	2.47	.05
(2) T and F (additive)	$R^2_{T,F}$	.0560	3	1.67	ns
(a) T adjusted for F	$R^2_{T,F} - R^2_F$	.0223	2	1.00	ns
(b) F adjusted for T	$R^2_{T,F} - R^2_T$	.0594	1	5.31	.05
(3) Interaction T X F	$R^2_{T,F,TF} - R^2_{T,F}$	.0824	2	3.68	.05
(4) Residual	$1-R^2_{T,F,TF}$	.8616	77		

favorability of student perceptions of the instructional treatment and formal operational capability indicated that low formal capability V-M students were more favorable in their perceptions of the instructional treatment experienced than were the V-P or control students in their perceptions of their instruction. The opposite opinions, however, were manifested by the high formal groups with the V-M group responding with only average favorability toward the instruction received, while their formal counterparts in the other two treatments showed high favorability.

Examination of each group's response to the four sub-categories of items on the opinion survey reveals patterns consistent with those summarized in Figure 2. A bivarate regression of each sub-category (Interest, Appropriate Difficulty, Preferred Mode, and Clarity) for each group is provided in Table 5 with corresponding graphs in Figure 3. Certain trends, though not necessarily significant are noted here: V-M group interest remained high across formal capability; clarity of directions was a problem for V-M group students, but less so for V-P students; V-P students generally perceived the material as too easy, while V-M students perceived it as not too easy and not too difficult; and under preferred mode, V-M students "wanted more science lessons like these," while the other two groups didn't like learning science "this way."

Drawing broad conclusions from the results cited would be inappropriate given the design limitations of the study. The study is more an example of evaluation research, useful for decision making within a school system rather than a solid addition to the basic research on instruction.

Granting these limitations, the instruments used and the trends revealed should be useful in decision making about the appropriateness of kinds of instructional materials and strategies for intact adolescent age, physical

Table 5

Bivariate Regression of Interest, Clarity, Appropriate Difficulty and Preferred Mode (Subscales of Student Perception of Instructional Treatment) with Formal Reasoning for Each Treatment

Interest

Treatment	n	R	R^2	B	Constant	p
Verbal-Manipulative	47	-.10	.01	-.03	5.37	.24
Verbal-Pictorial	13	.02	.00	.01	4.50	.48
Control	57	-.02	.00	-.01	4.63	.43

Clarity

Treatment	n	R	R^2	B	Constant	p
Verbal-Manipulative	43	.11	.01	.03	4.50	.25
Verbal-Pictorial	14	.46	.21	.11	4.65	.05
Control	55	.32	.10	.17	3.62	.01

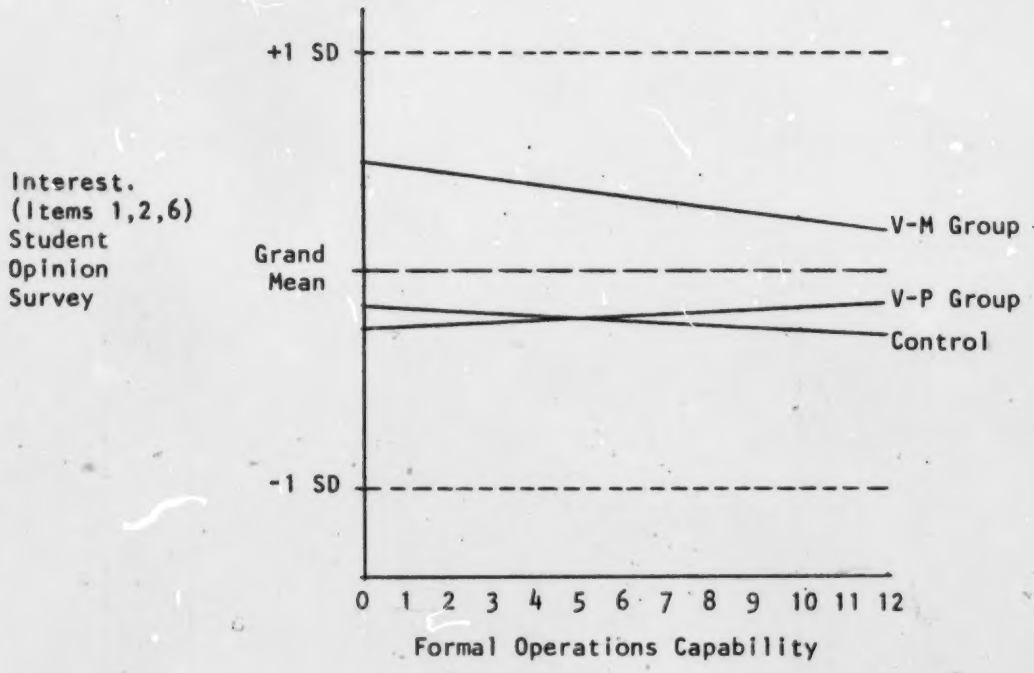
Appropriate Difficulty

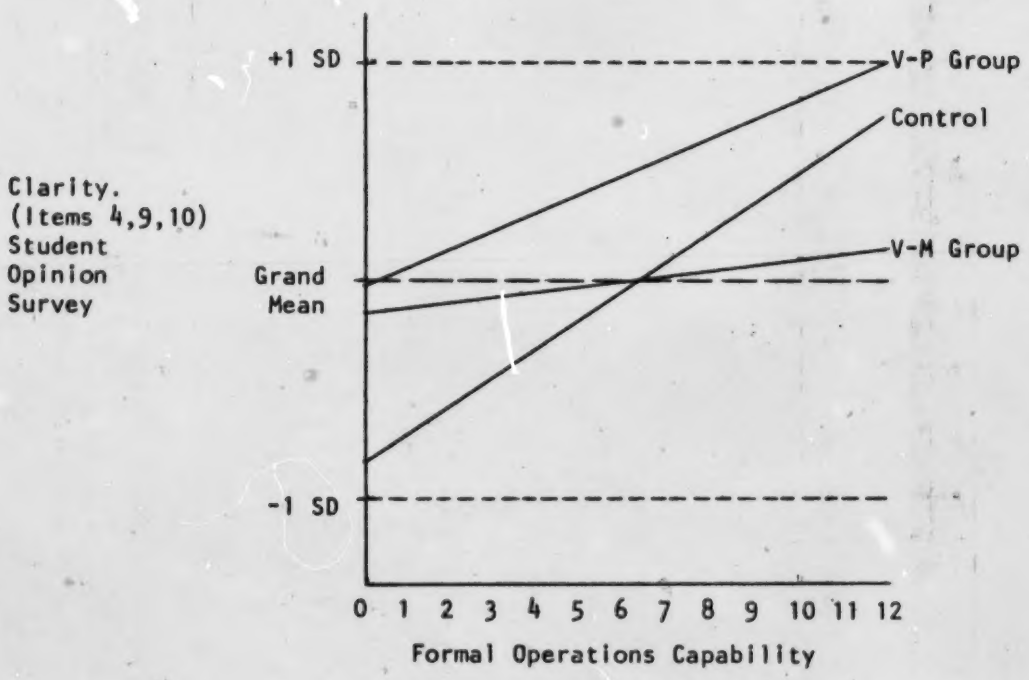
Treatment	n	R	R^2	B	Constant	p
Verbal-Manipulative	44	.00	.00	.00	5.68	.50
Verbal-Pictorial	12	.43	.19	.07	4.59	.08
Control	47	.32	.10	.10	4.80	.02

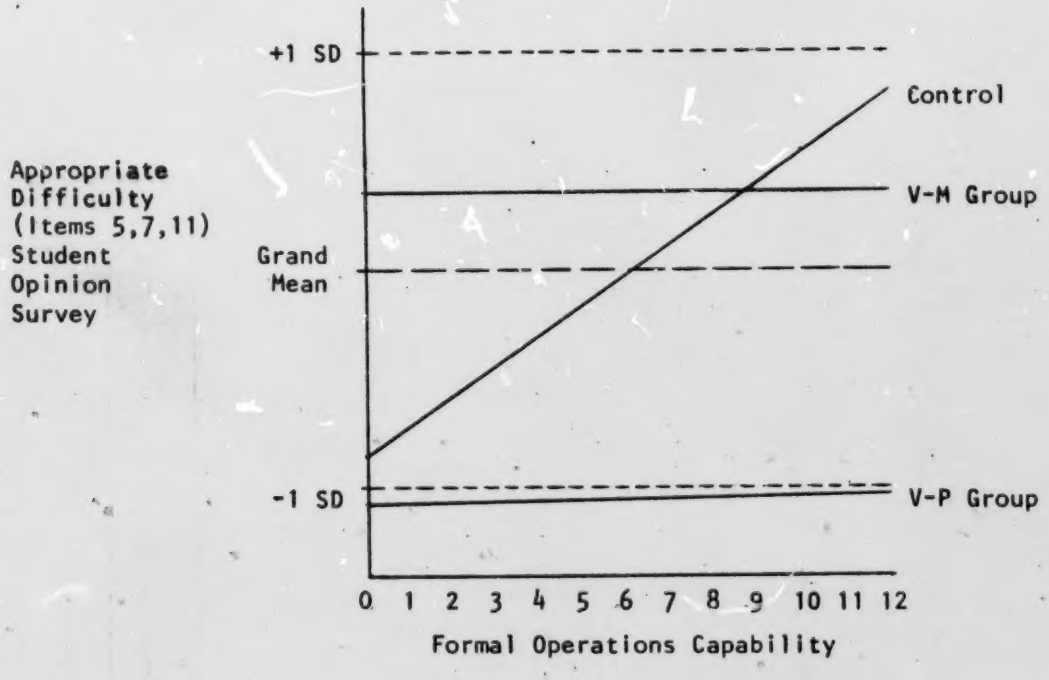
Preferred Mode

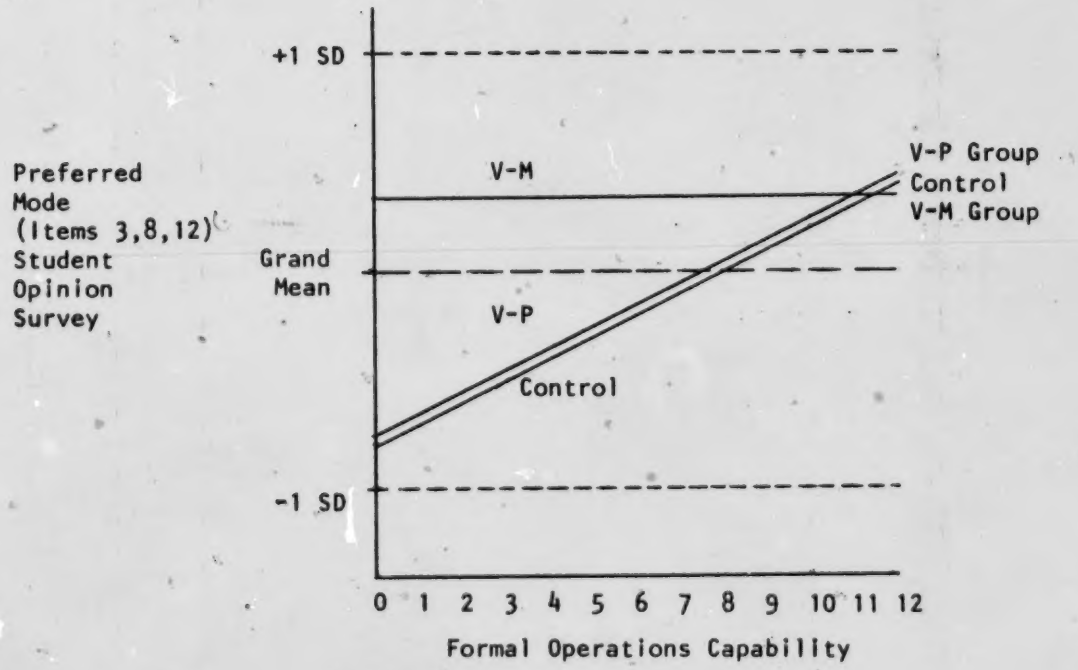
Treatment	n	R	R^2	B	Constant	p
Verbal-Manipulative	49	-.01	.00	.00	5.60	.47
Verbal-Pictorial	15	.48	.23	.11	4.42	.04
Control	52	.23	.05	.11	4.39	.05

Figure 3


Interest.
(Items 1,2,6)
Student
Opinion
Survey
+1 SD
Grand
Mean
-1 SD
V-M Group
V-P Group
Control
0 1 2 3 4 5 6 7 8 9 10 11 12
Formal Operations Capability


Clarity.
(Items 4,9,10)
Student
Opinion
Survey
+1 SD
Grand
Mean
-1 SD
V-P Group
Control
V-M Group
0 1 2 3 4 5 6 7 8 9 10 11 12
Formal Operations Capability


Appropriate Difficulty (Items 5,7,11) Student Opinion Survey
+1 SD
Grand Mean
-1 SD
Control
V-M Group
V-P Group
0 1 2 3 4 5 6 7 8 9 10 11 12
Formal Operations Capability


Preferred Mode (Items 3,8,12) Student Opinion Survey
+1 SD
Grand Mean
-1 SD
V-M
V-P
Control
V-P Group
Control
V-M Group
0 1 2 3 4 5 6 7 8 9 10 11 12
Formal Operations Capability

science groups. The results suggest that changes in basic reasoning skills such as proportional reasoning are long term, highly dependent on general formal capabilities and probably responsive to a variety of instructional modes.

Short-term teaching strategies using manipulatives have their primary value in the favorable perceptions of science instruction they engender in low formal capability students. This outcome alone justifies the use of such materials since, without positive attitudes, such students will insure that this last mandatory course in physical science is the last contribution that physical science will make to the growth of their formal reasoning skills.

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Appendix

Instrument to Measure Favorability of Student Perception of Instructional Treatment (Student Opinion Survey)

Scoring: Favorable responses, indicated with an asterisk, were scored as 2 points; unfavorable responses, 1 point. Subscale classification: Interest (1,2,6); Clarity (4,9,10); Appropriate Difficulty (5,7,11); Preferred Mode (3,8,12).

Directions: You have just completed a set of lessons about the density of objects. Read each statement below and circle the word agree or disagree. Each statement refers only to the lessons on density.

1.	Time seemed to go by quickly when I was working on these lessons.	agree *	disagree
2.	These lessons were boring.	agree	disagree *
3.	I would like more science lessons with materials like these.	agree *	disagree
4.	The challenges (experiments) need more directions.	agree	disagree *
5.	These lessons were too easy for me.	agree	disagree *
6.	It was hard to keep my mind on these lessons.	agree	disagree *
7.	Learning these ideas from other materials would have been easier.	agree	disagree *
8.	I prefer to do lessons like these rather than just read about them.	agree *	disagree
9.	The teacher should have prepared us more for these lessons.	agree	disagree *
10.	The directions were clear enough.	agree *	disagree
11.	These lessons were too difficult for me.	agree	disagree *
12.	I enjoy learning science this way.	agree *	disagree